CS130 : Computer Graphics

Lecture 2: Graphics Pipeline

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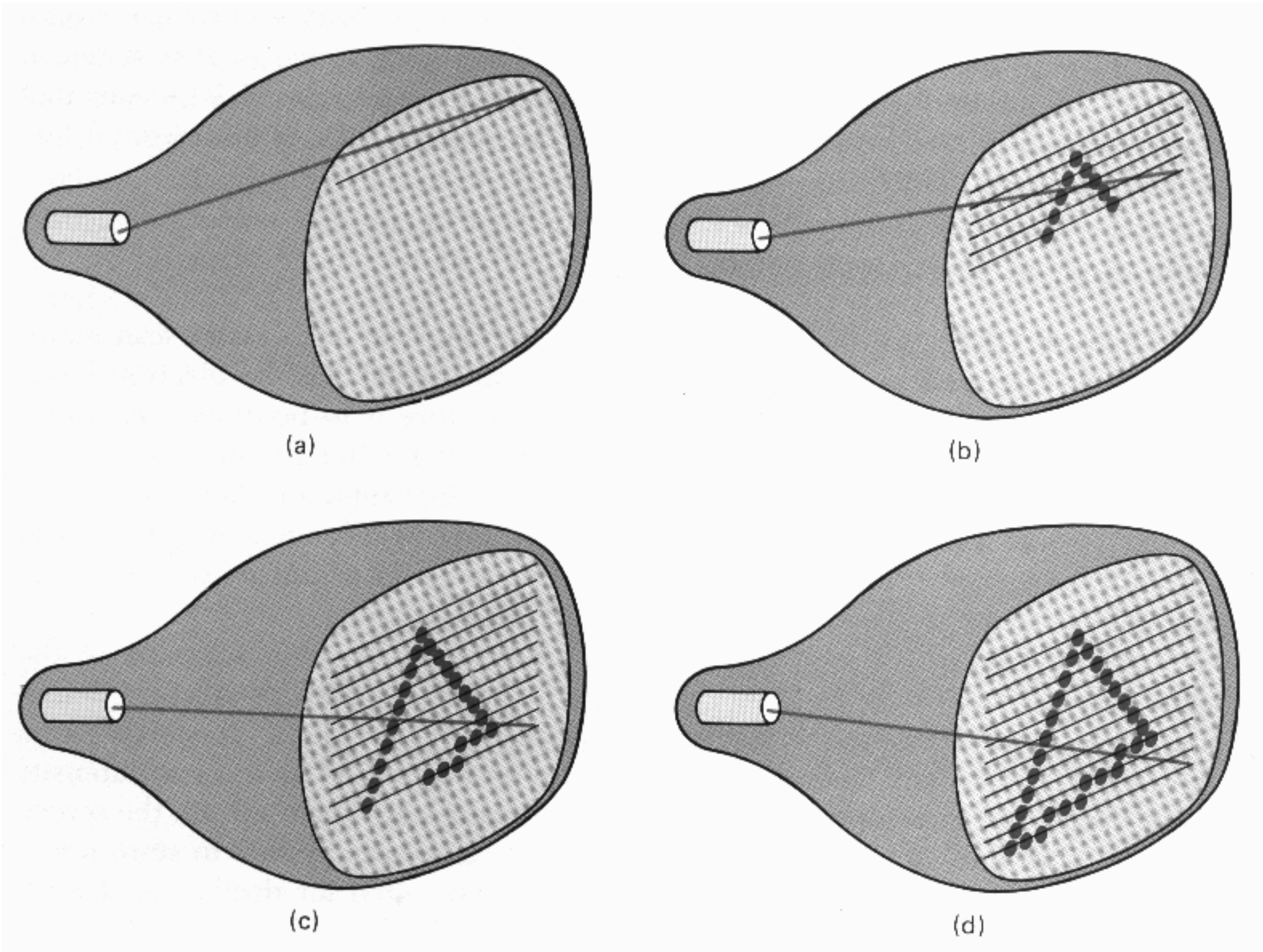
Raster Devices and Images

Raster Devices

- raster displays show images as a rectangular array of pixels
- most printers are also raster devices
  - image is made by depositing ink at points on a grid
- digital cameras - have image sensors made of grid of light-sensitive pixels (2D array)
- scanner - linear array of pixels swept across page to create grid of pixels (1D array)

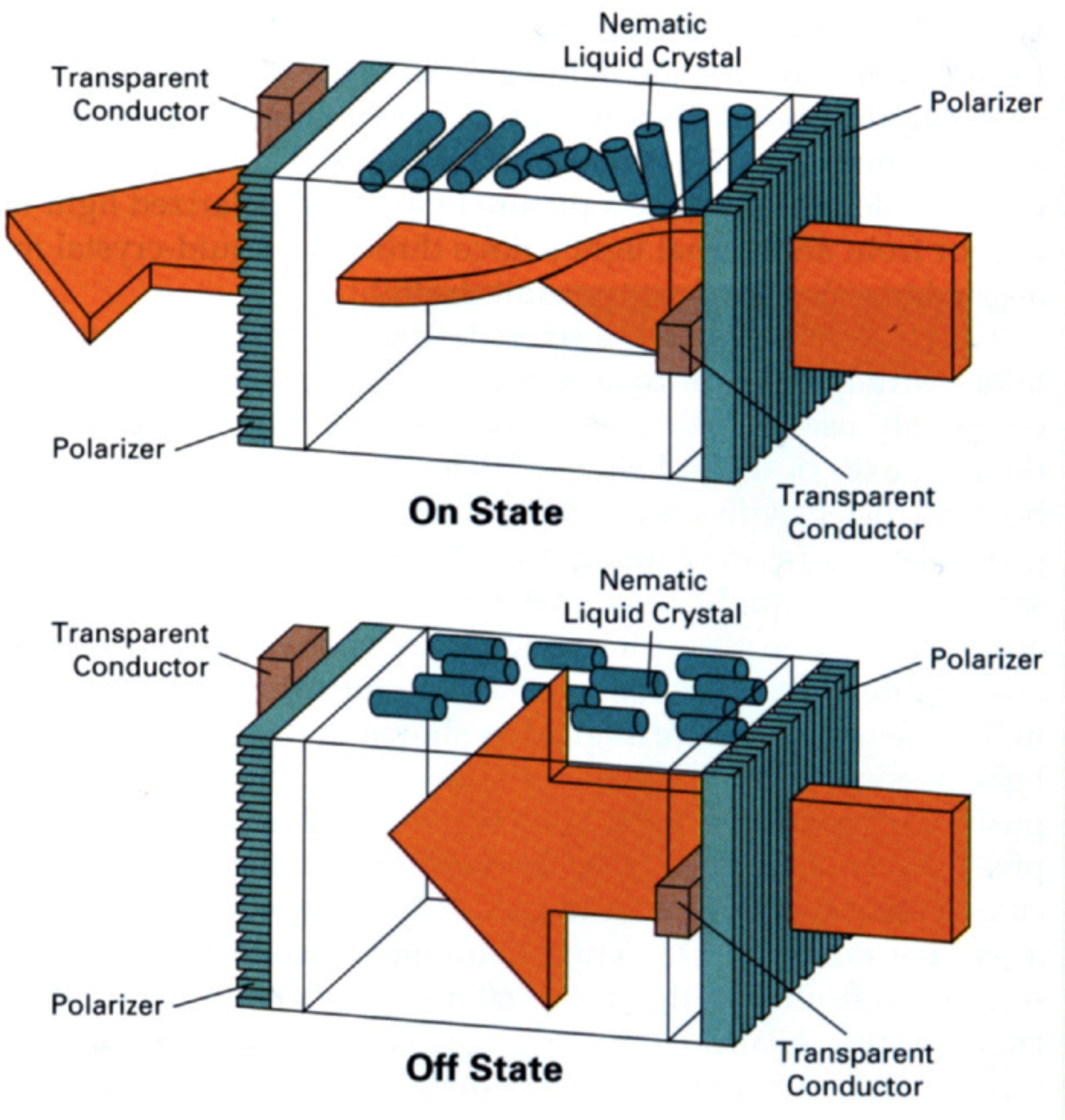
Raster Display



Hearn, Baker, Carithers

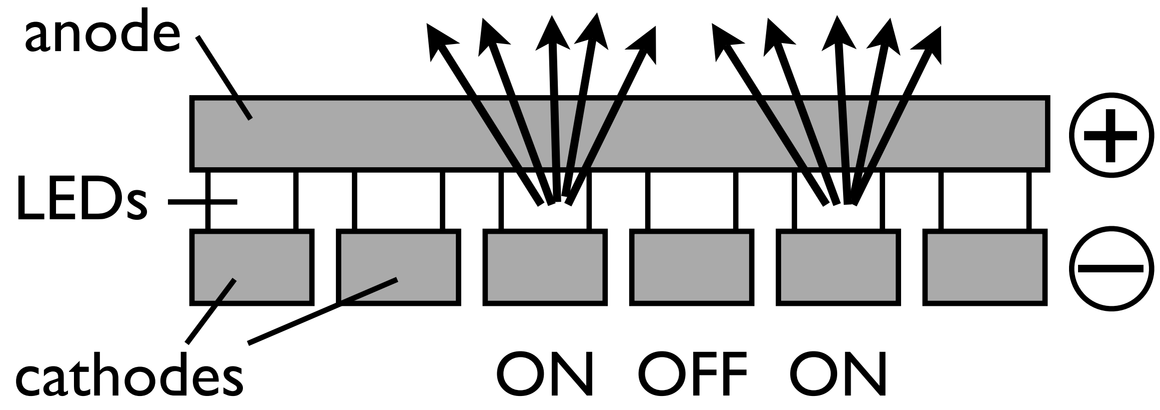
virtually all graphics system are **raster based,** meaning the image we see is a **raster of pixels**
or a rectangular array of pixels
Here a raster scan device display an image as a set of discrete points across each scanline

Transmissive vs. Emissive Display



[H&B, Fig. 2-16]

LCD

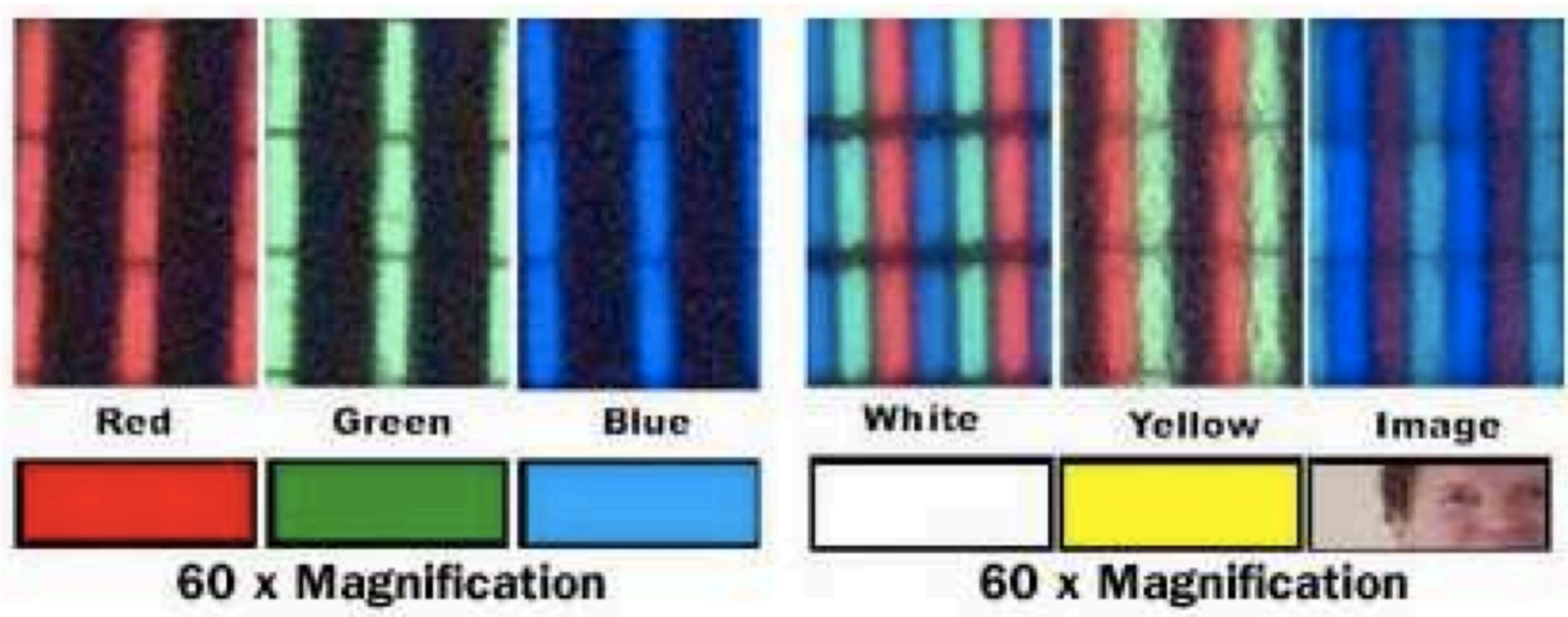


LED

Displays are either **transmissive** or **emissive**

one pixel of an LCD display:
(LEFT)In the **off state** the front polarizer blocks all the light that passes the back polarizer
in the **on state** the liquid crystal rotates the polarization of the light so it can pass through the front polarizer
the degree of rotation can be adjusted by an applied voltage
(RIGHT) LED display

Raster Display



red, green, blue subpixels

get different colors by mixing red, green, and blue
this is from an LCD monitor
printers are also raster-based. image is made out of points on a grid

What is an image?

Continuous image

$$I : R \rightarrow V$$

$$R \subset \mathbb{R}^2$$

$V = \mathbb{R}^+$ (grayscale)

$V = (\mathbb{R}^+)^3$ (color)

An (continuous) image is a function defined over some 2D area, that maps points to intensity level

What is an image?

Sampled image

$$I : R \to V$$

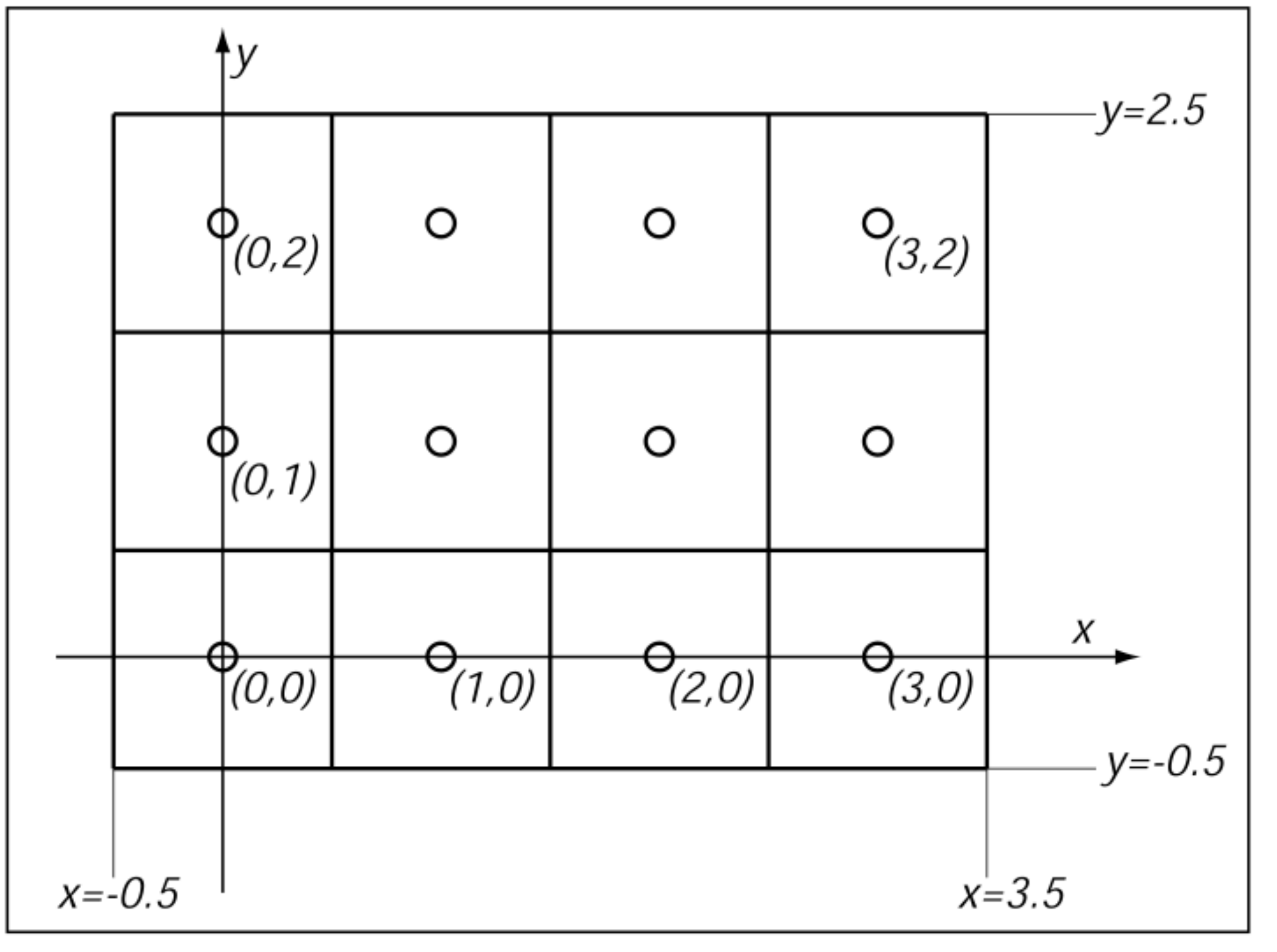
$$R \subset \mathbb{Z}^2$$

$V = [0, 1]$ (grayscale)

$V = [0, 1]^3$ (color)

n_x = number of columns

n_y = number of rows



$$R = [-0.5, n_x - 0.5] \times [-0.5, n_y - 0.5]$$

each pixel value represents the **average color** of the image over that pixel's area.

Bit depth - defined by device standards

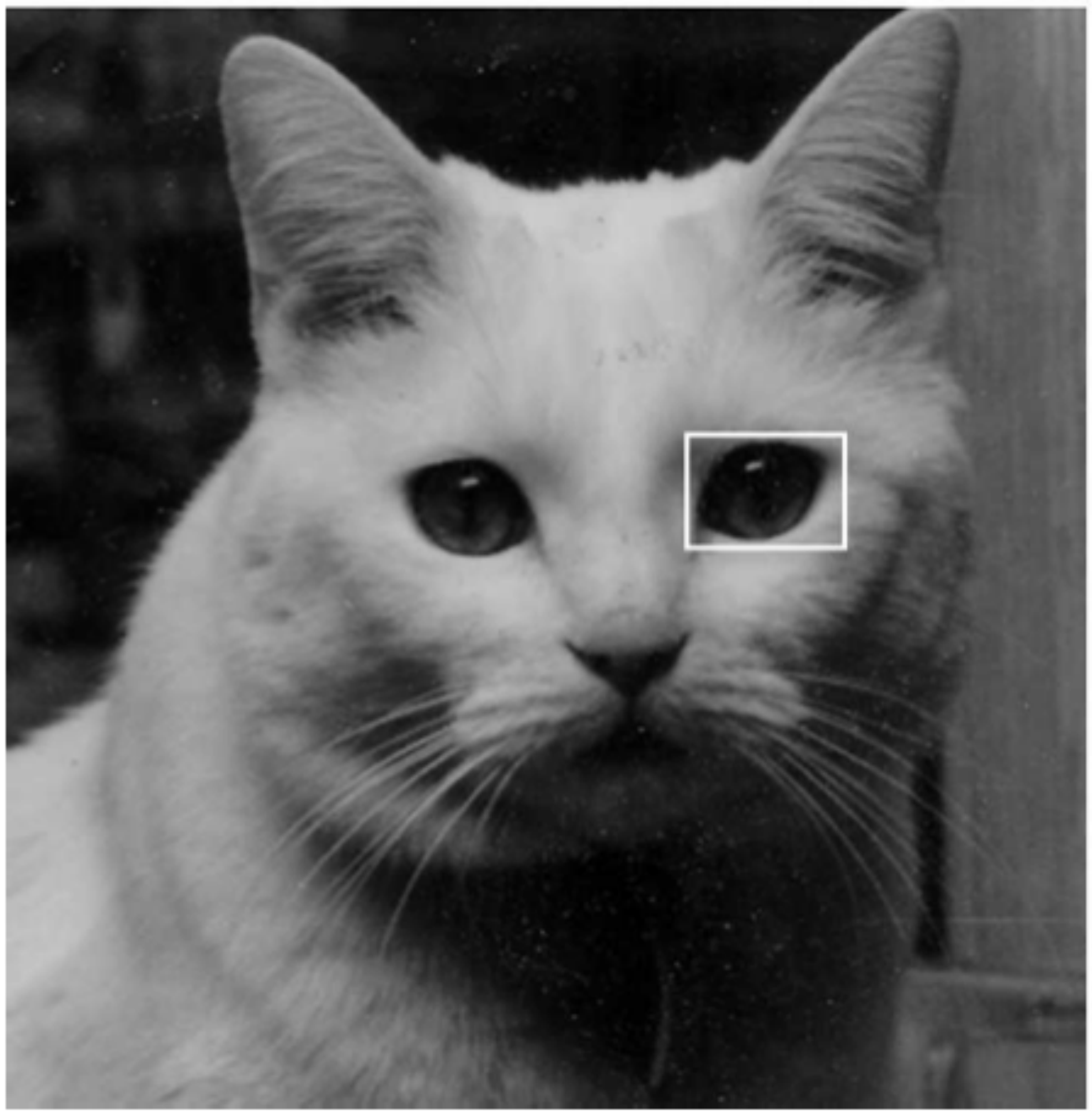
Bit-Depth	Number of Colors
1	2 (monochrome)
2	4 (CGA)
4	16 (EGA)
8	256 (VGA)
16	65,536 (High Color, XGA)
24	16,777,216 (True Color, SVGA)
32	16,777,216 (True Color + Alpha Channel)

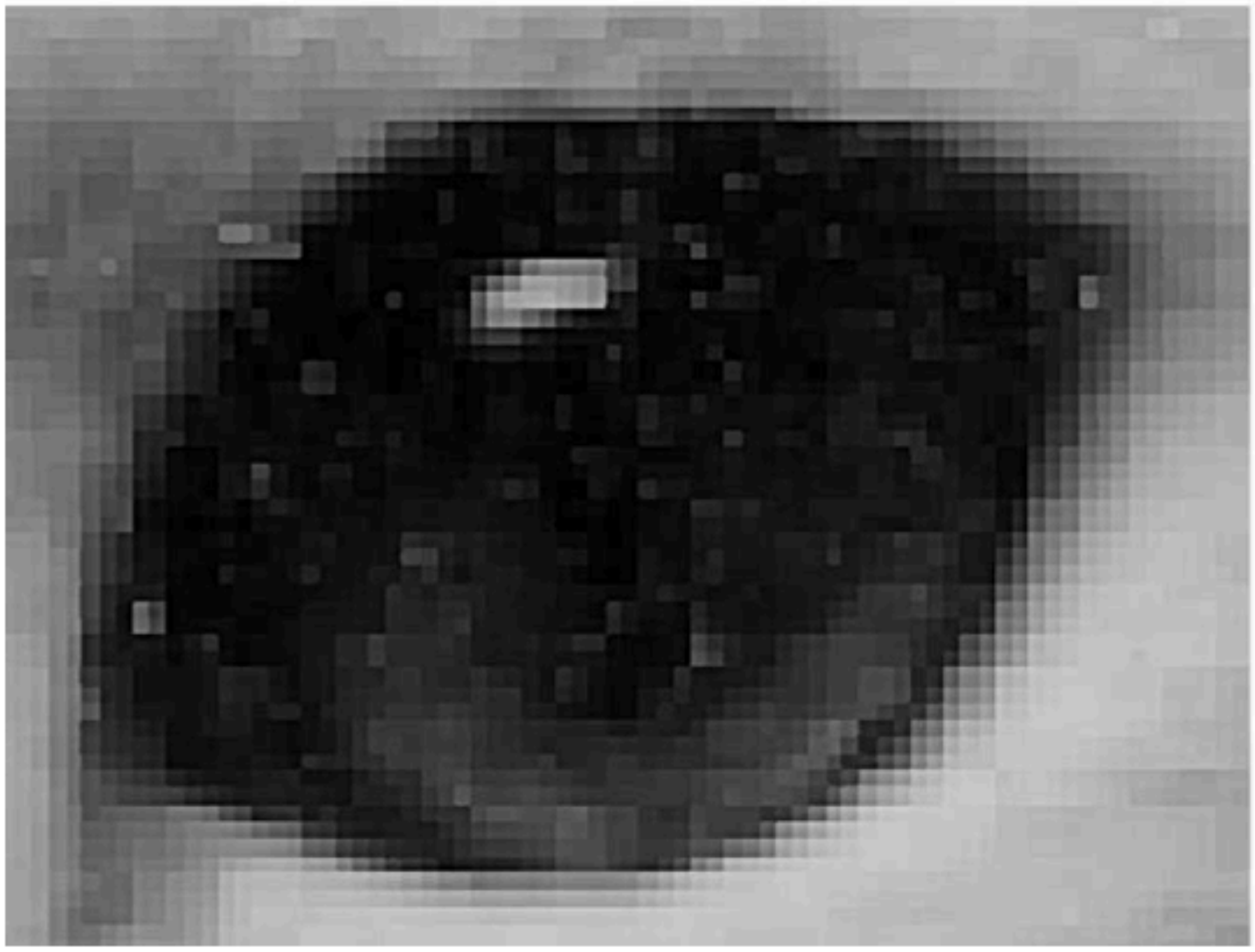
(Note alpha)

(Humans can perceive ~10,000,000 colors)

in practice, it is sufficient for pixels to have a bounded range e.g., [0,1]
They are represented in integers

Raster Image

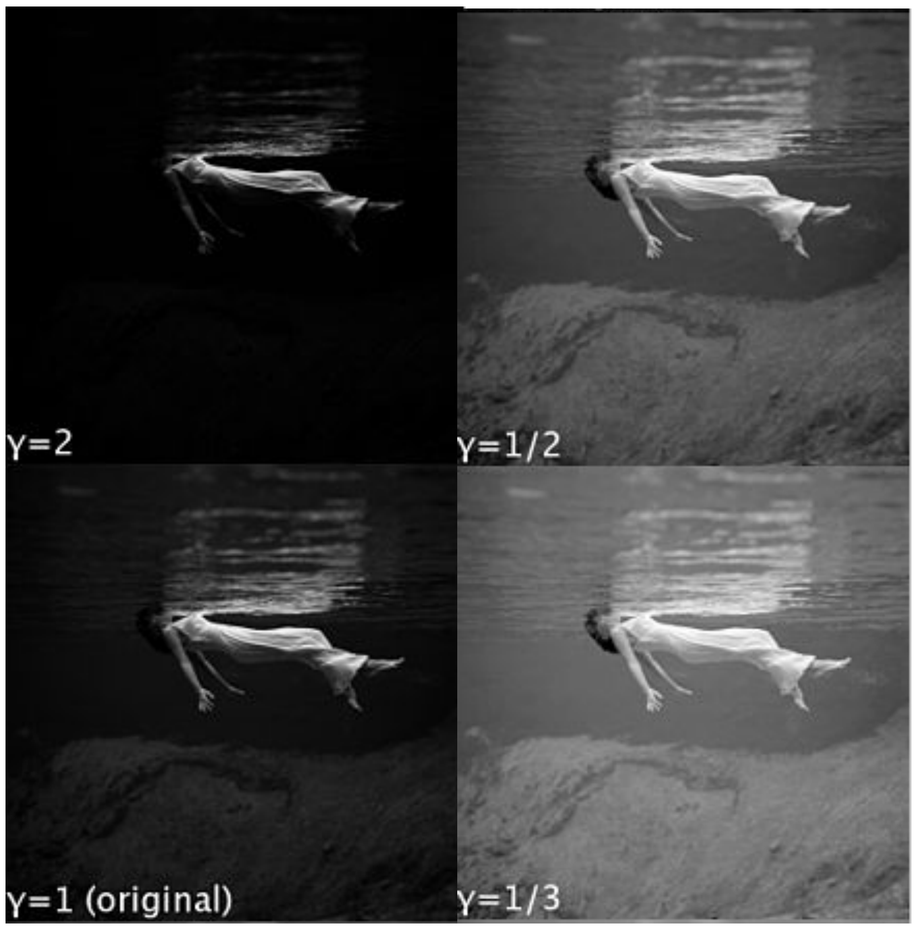


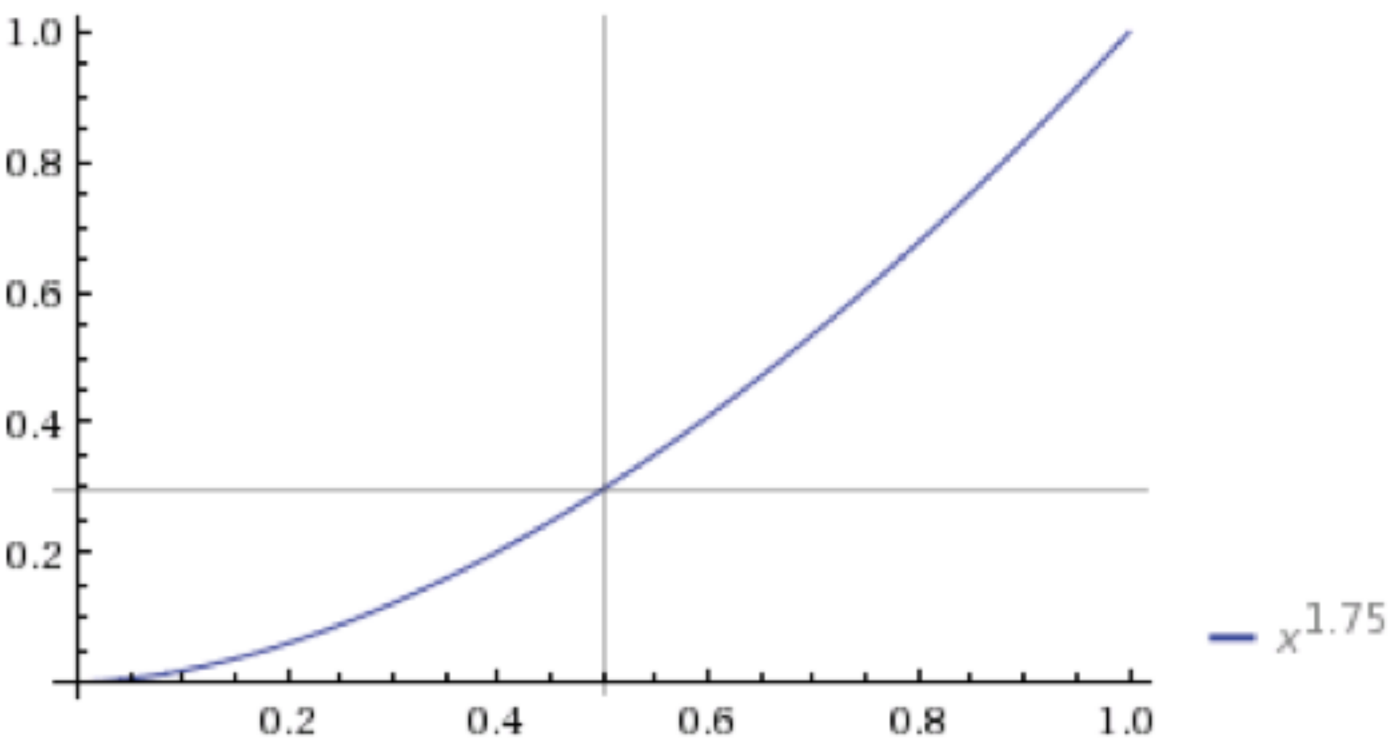


A **raster image** is 2D array storing pixel values at each pixel (picture element)
3 numbers for color
alternative: **vector image** -- essentially a set of instructions for rendering an image

Monitor Gamma

displayed intensity = (max intensity) a^γ



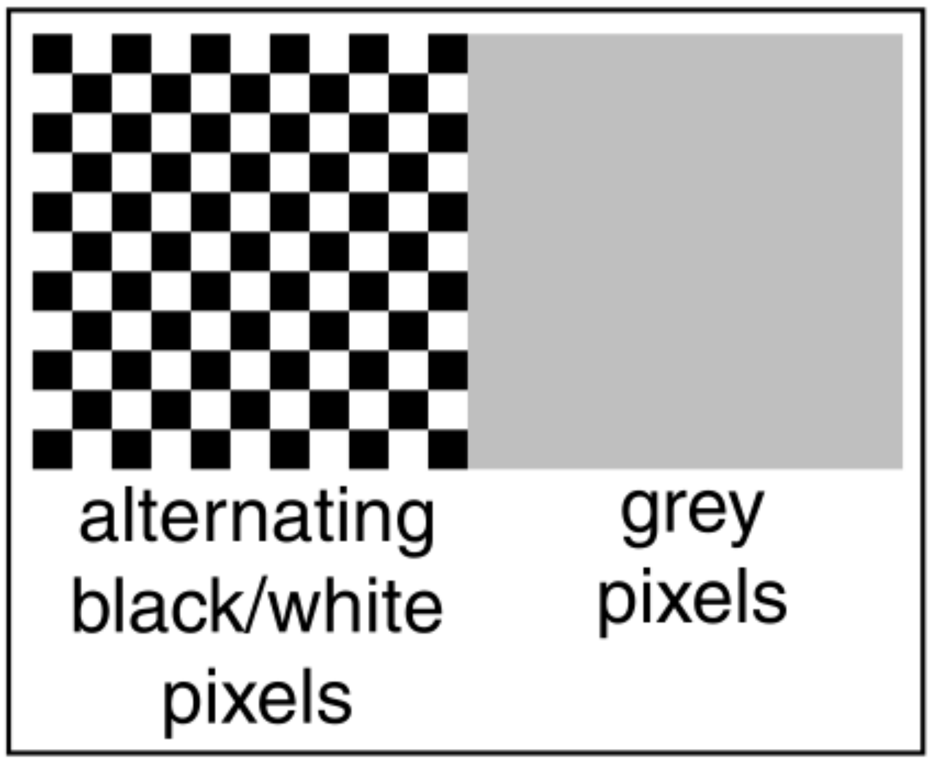


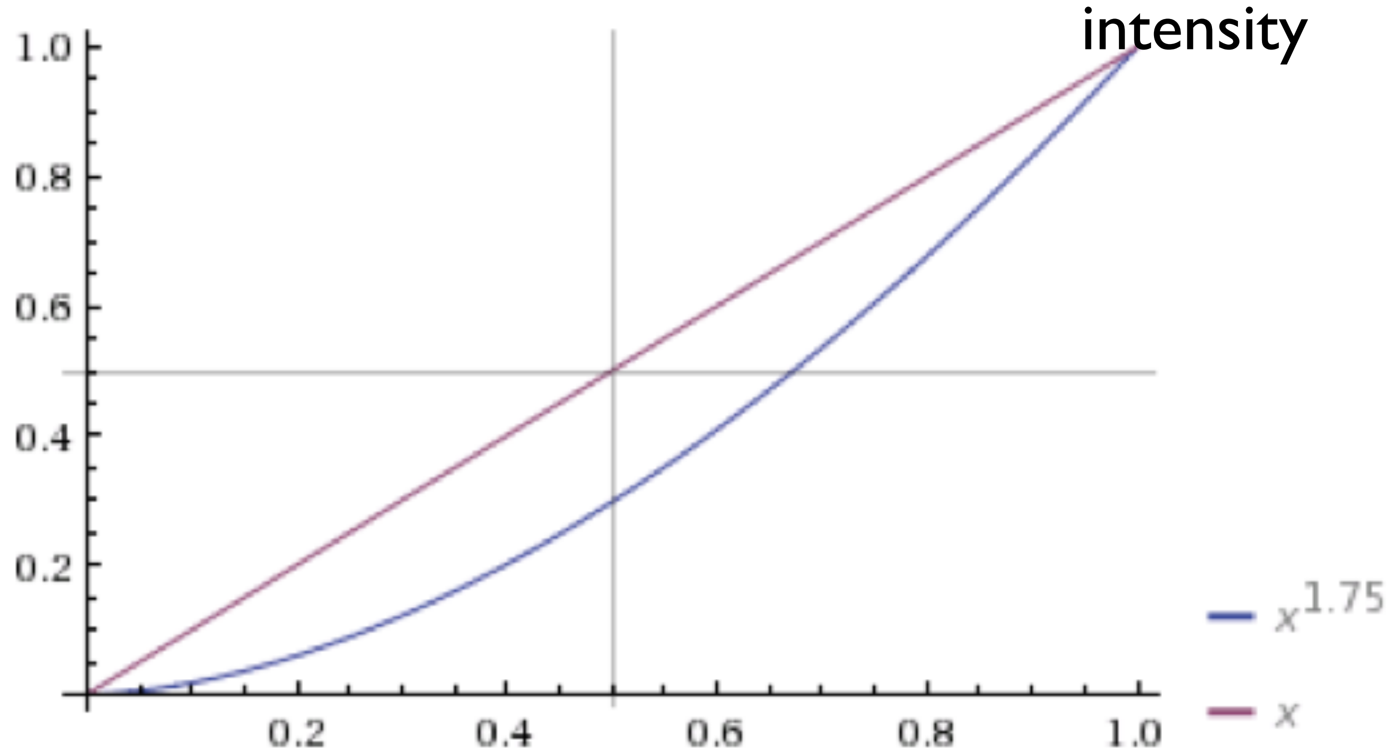
monitors convert pixel values, a, into displayed intensities
monitors are nonlinear with respect to input

Gamma Correction

displayed intensity = (max intensity)$\Big(\underbrace{a^{\frac{1}{\gamma}}}\Big)^{\gamma}$

gamma-corrected intensity





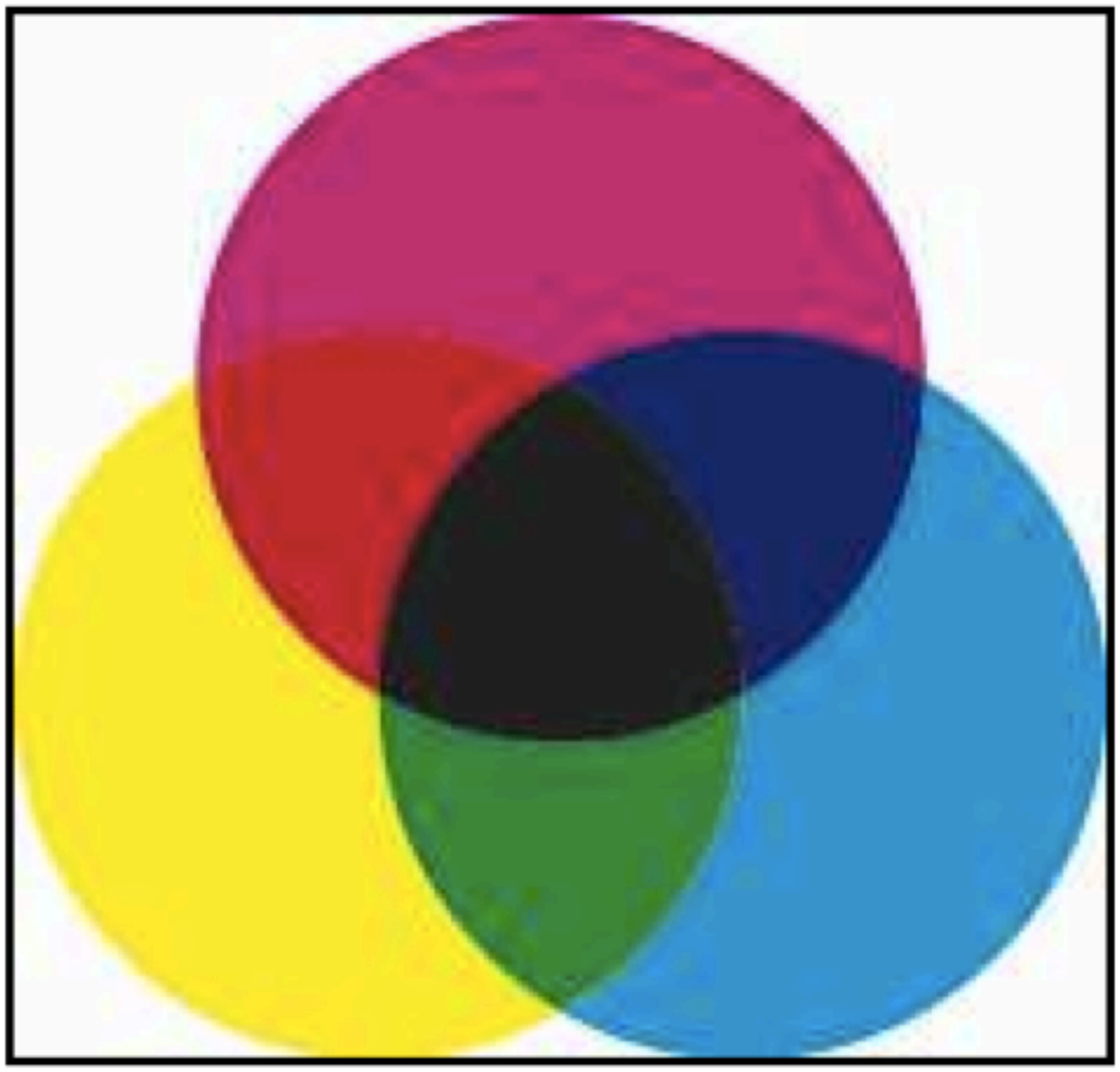
find gamma using, e.g., checkerboard

then gamma-correct the input

find gamma, so that you can give the monitor a^{1/\gamma}
- find a such that a^{\gamma} = .5 through checkerboard test and solve for gamma

Color representation

additive

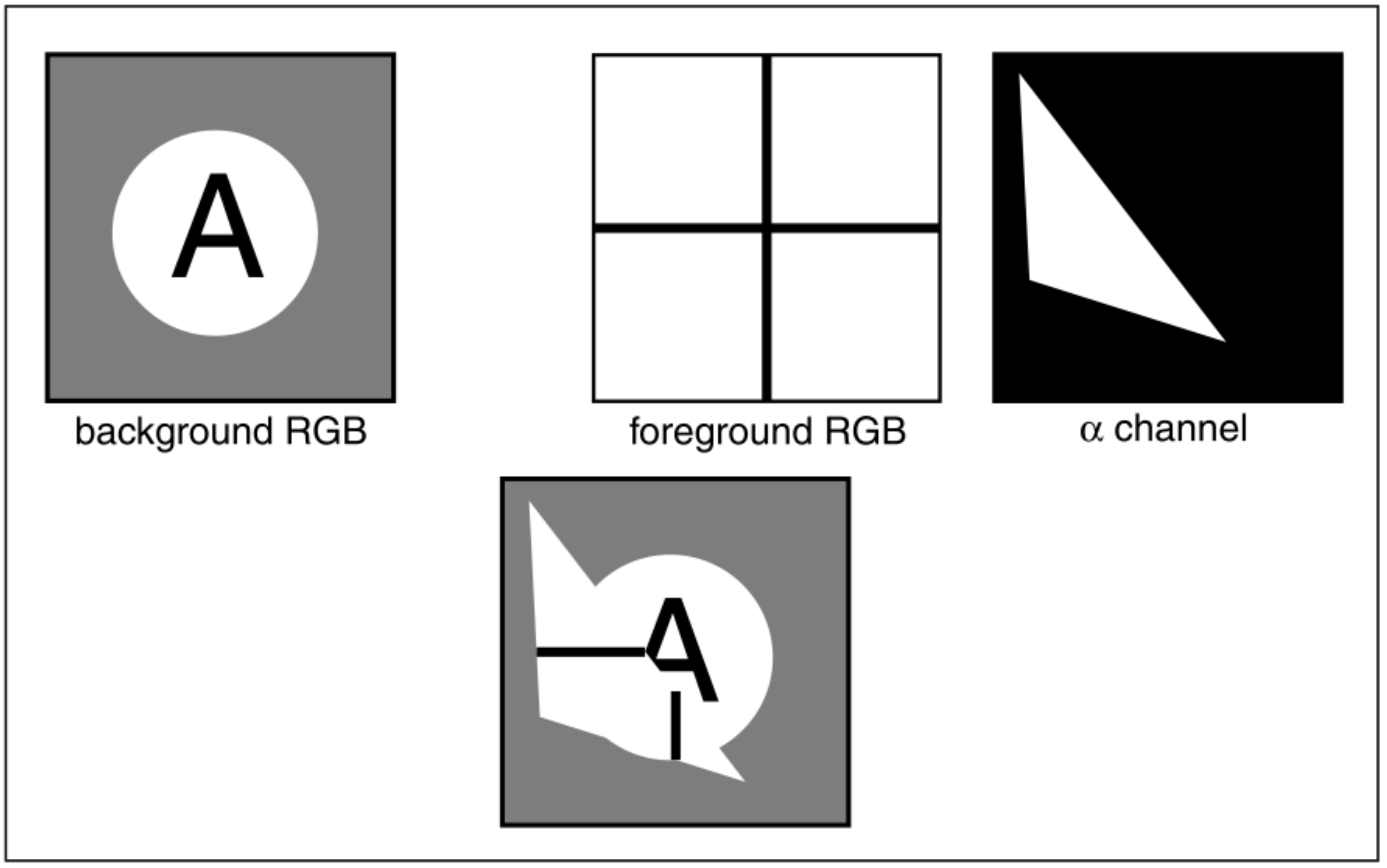


subtractive

additive color – Primary colors are red, green, blue. form a color by adding these. CRTs, projectors, LCD displays, positive film
subtractive color – form a color by filtering white light with cyan, magenta, and yellow filters printing, negative film

Alpha Channel

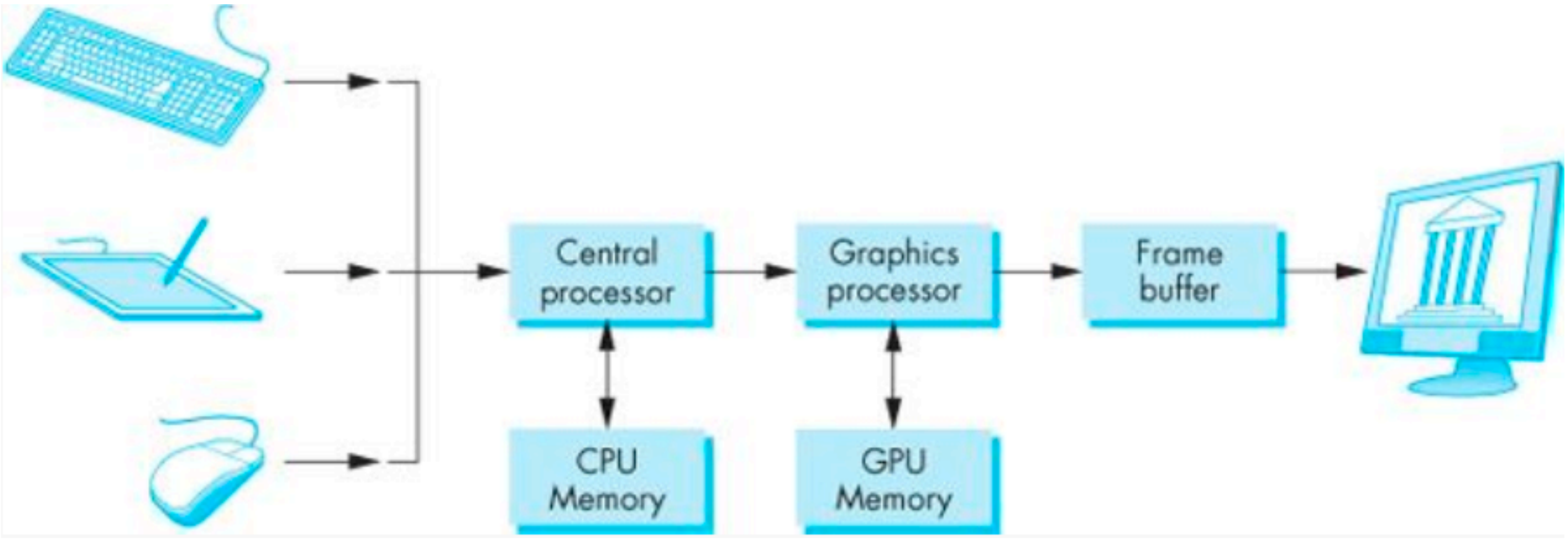
$$\mathbf{c} = \alpha \mathbf{c}_f + (1 - \alpha)\mathbf{c}_b$$



Compositing: two different interpretations: **pixel coverage** (fraction of pixel covered) and **blending**

Graphics Pipeline

Modern graphics system



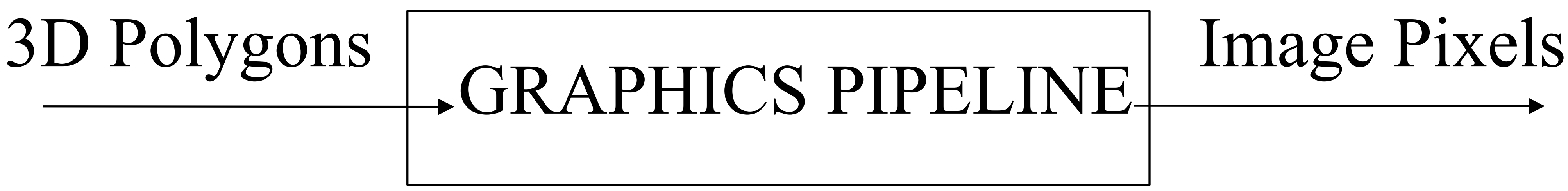
[Angel and Shreiner]

the pixels are stored in a location in memory call the **frame buffer**
frame buffer resolution determines the details in the image
- e.g., 24 bit color “full color”
- high dynamic range or HDR use 12 or more bits for each color

frame buffer = color buffers + other buffer

Z-buffer Rendering

- Z-buffering is very common approach, also often accelerated with hardware
- OpenGL is based on this approach



Choice of primitives

- Which primitives should an API contain?
  - small set - supported by hardware, *or*
  - lots of primitives - convenient for user

Choice of primitives

- Which primitives should an API contain?

➡**small set - supported by hardware**

- lots of primitives - convenient for user

Performance is in **10s millions polygons/sec** -- **portability, hardware support** key

Choice of primitives

- Which primitives should an API contain?

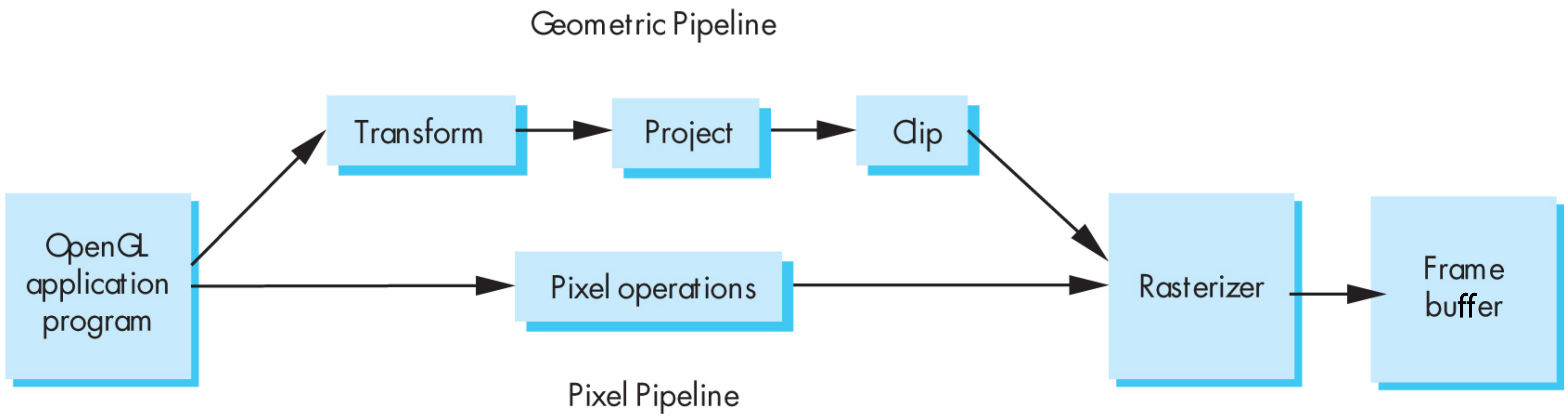
➡ **small set - supported by hardware**

- lots of primitives - convenient for user

GPUs are optimized for
points, **lines**, and **triangles**

Other geometric shapes will be built out of these

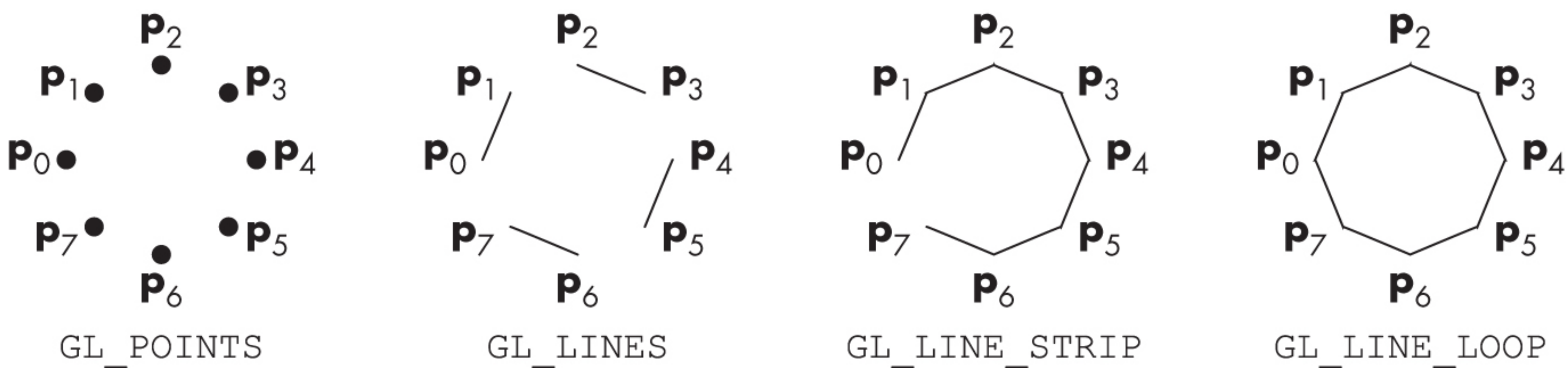
Two classes of primitives



[Angel and Shreiner]

Geometric : points, lines, polygons
Image : arrays of pixels

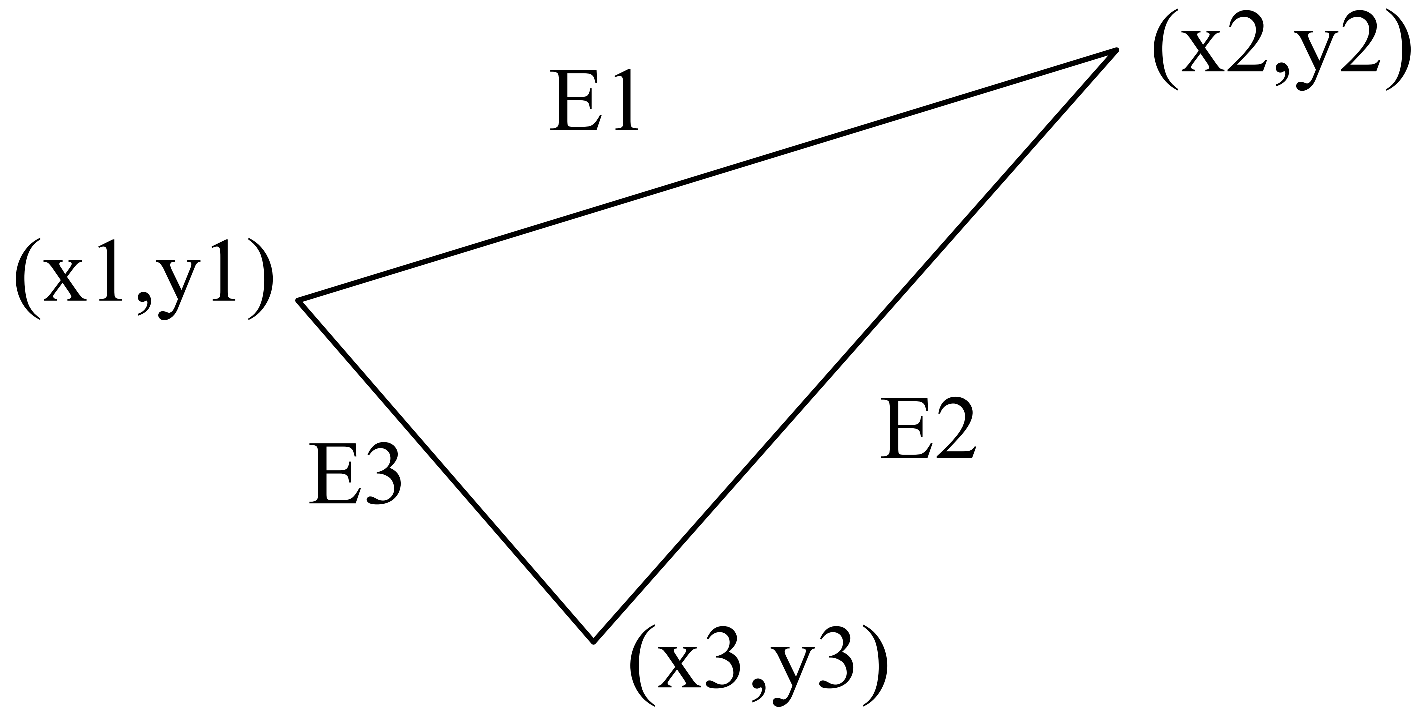
Point and line segment types



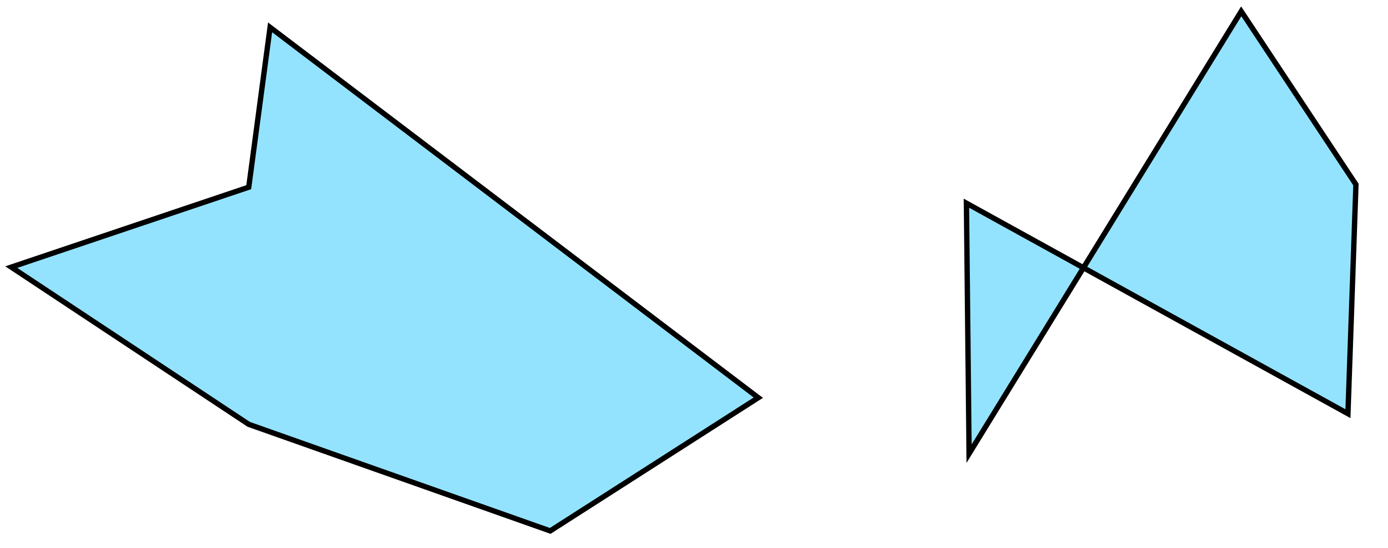
[Angel and Shreiner]

Polygons

- Multi-sided planar element composed of edges and vertices.
- Vertices (singular vertex) are represented by points
- Edges connect vertices as line segments



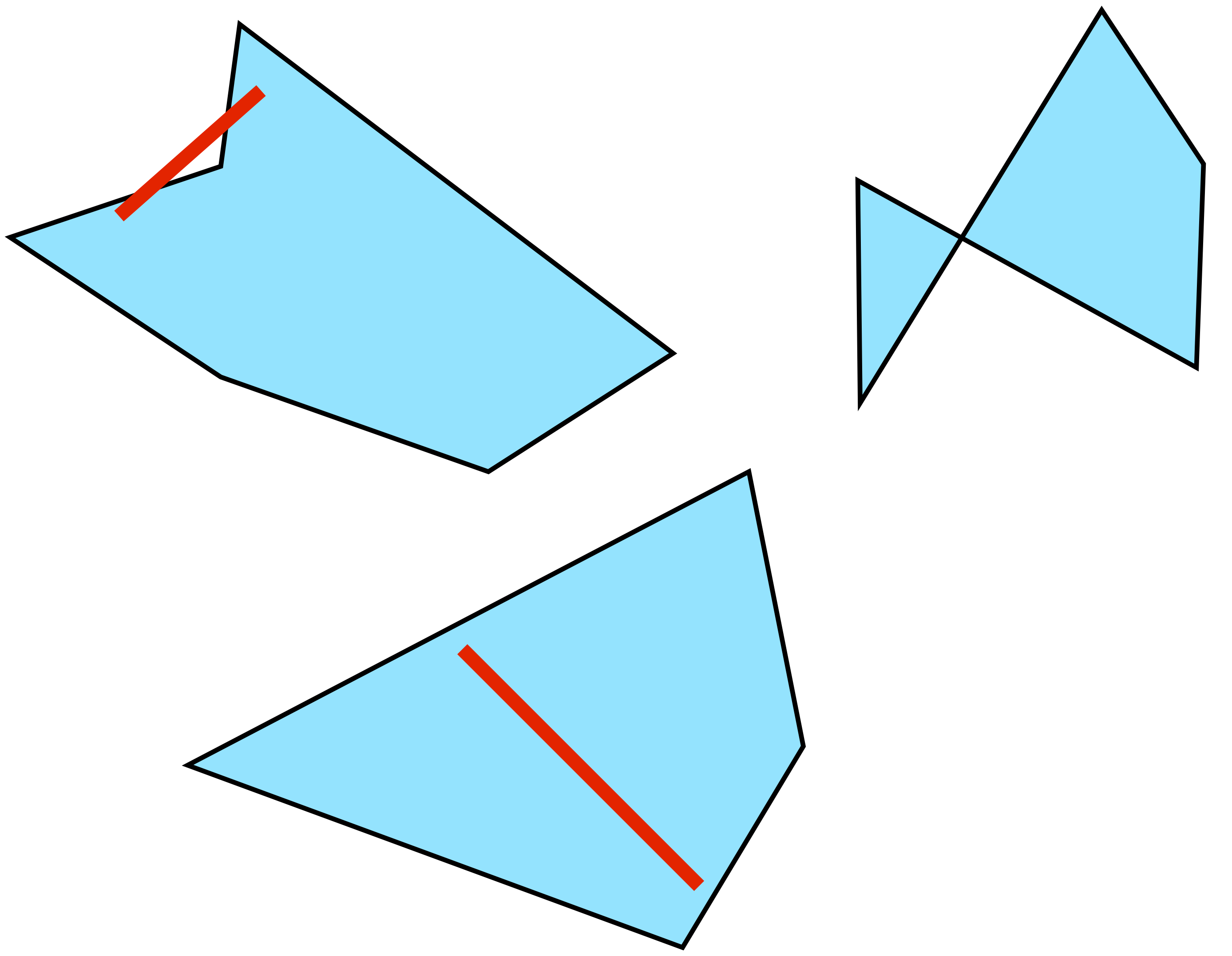
Valid polygons



- Simple
- Convex
- Flat

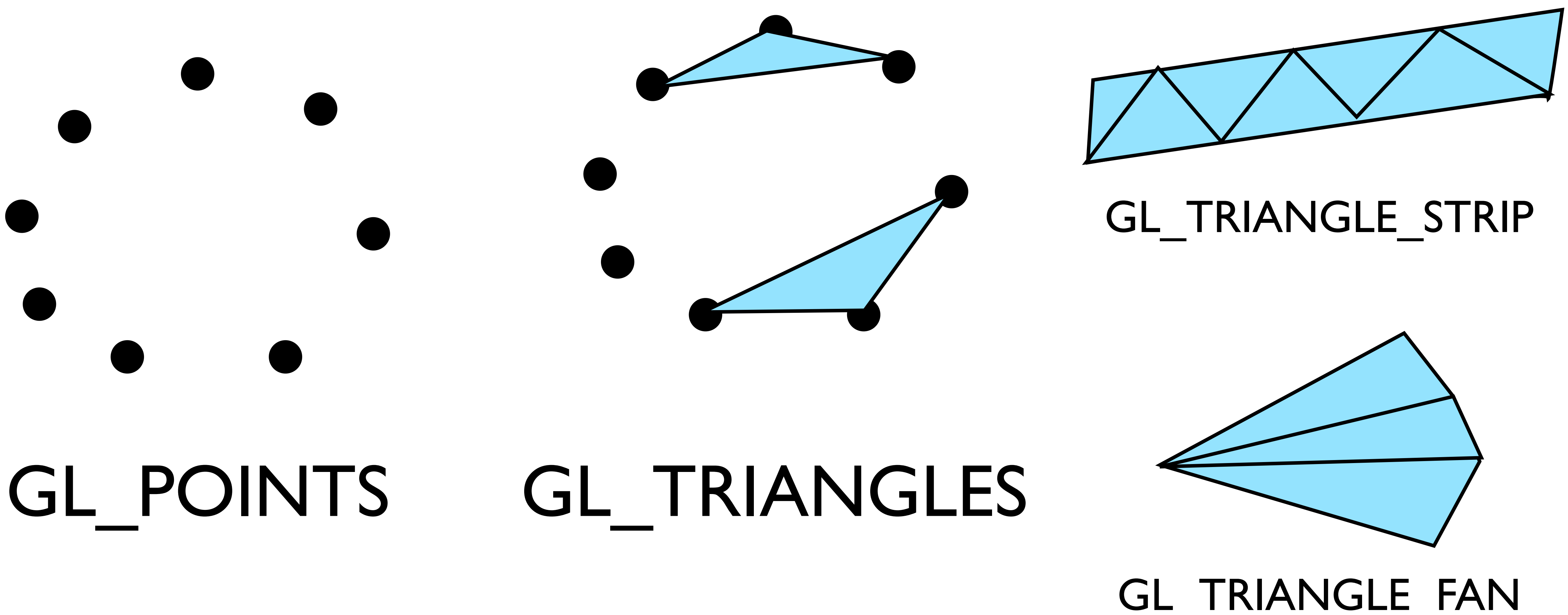
Valid polygons

- Simple
- Convex
- Flat

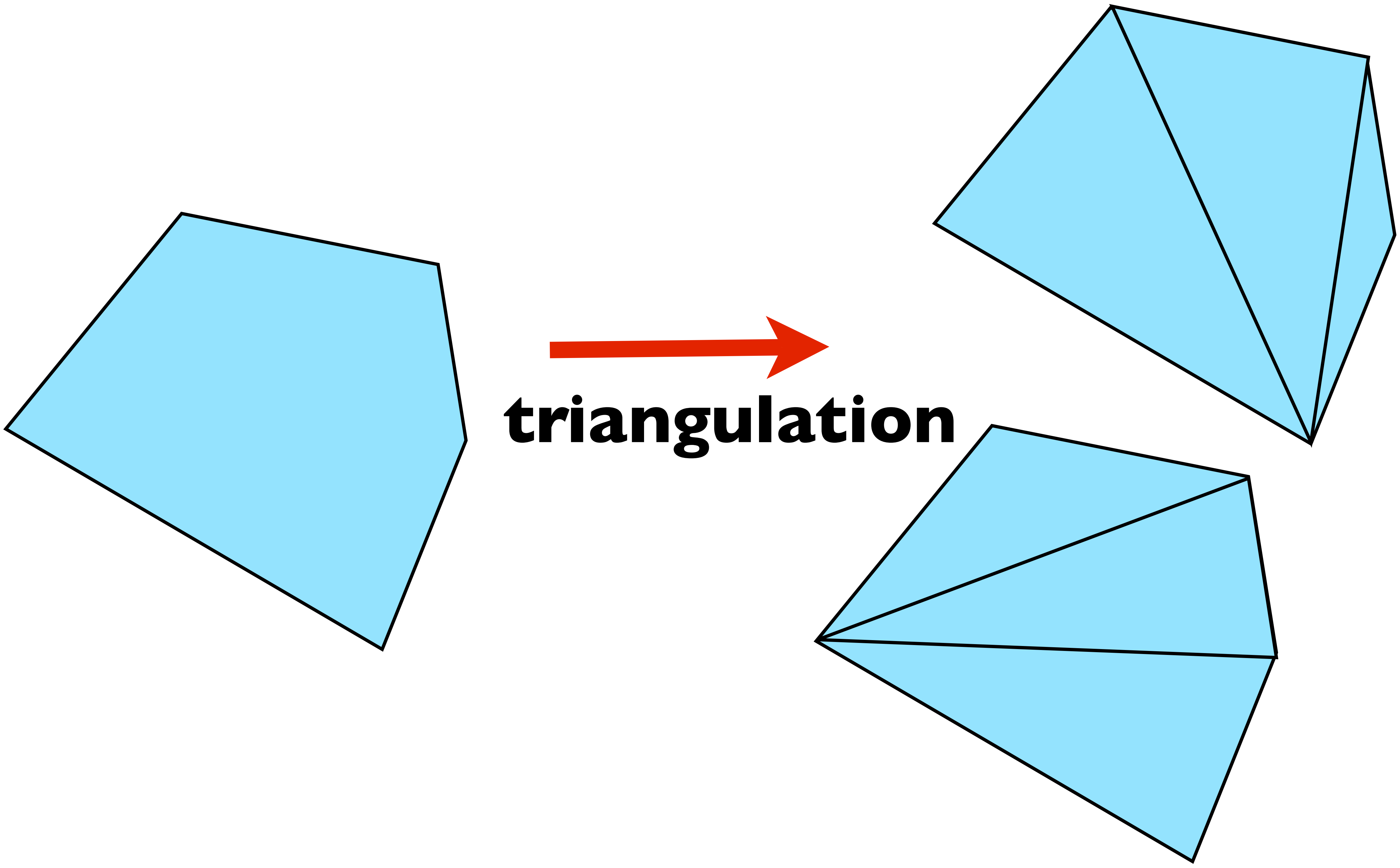


OpenGL polygons

- Only triangles are supported (in latest versions)



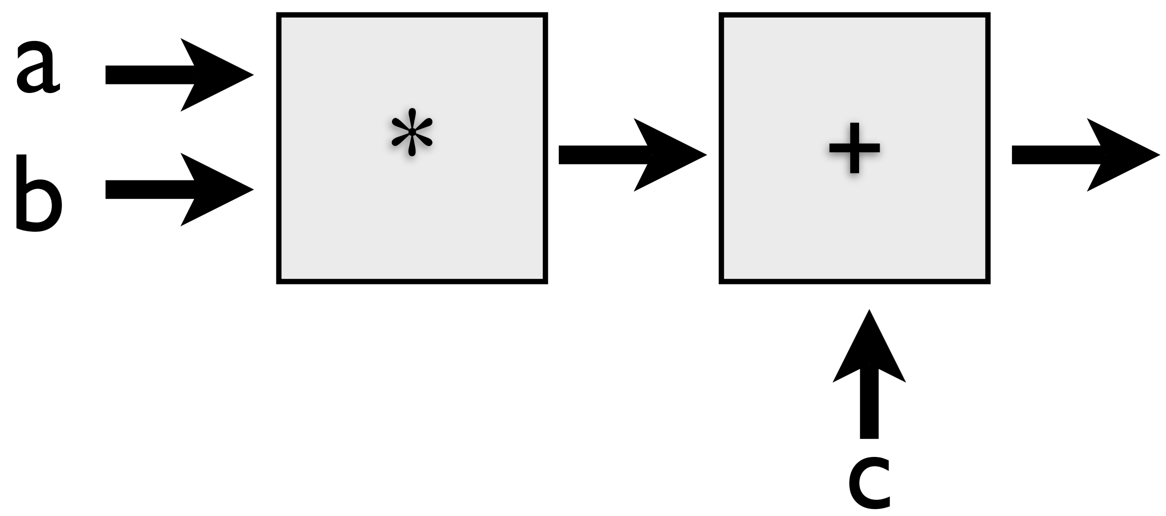
Other polygons

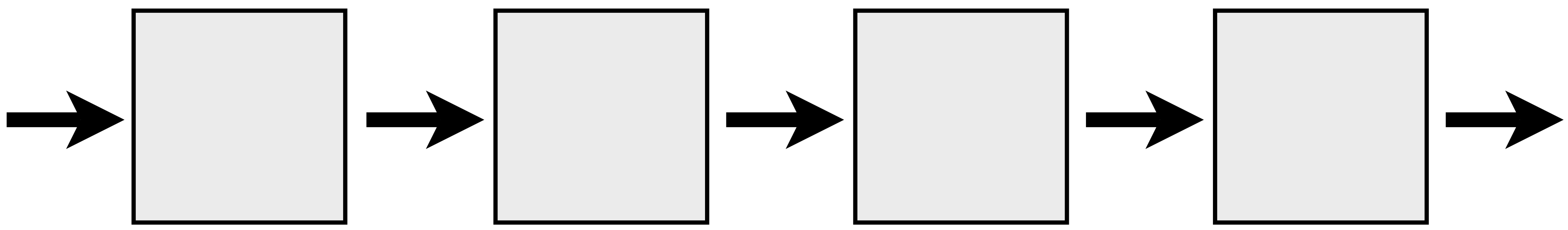


triangulation
as long as triangles are not **collinear**, they will be **simple**, **flat,** and **convex -- easy to render**

Pipelining operations

An arithmetic pipeline that computes c+(a*b)



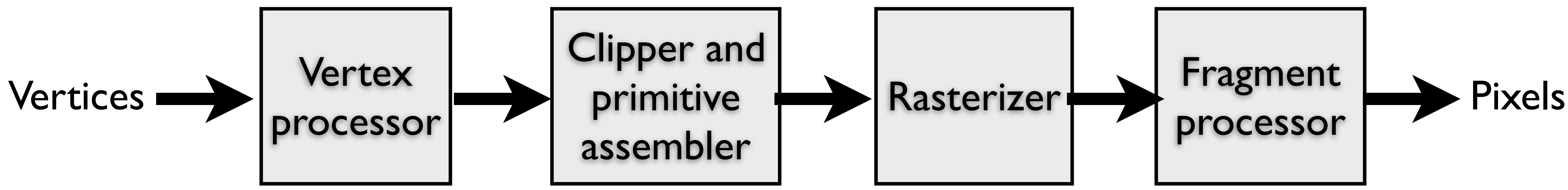


By pipelining the arithmetic operation, the **throughput**, or rate at which data flows through the system, has been **doubled**

If the pipeline had more boxes, the **latency, or time it takes one datum to pass through the system**, would be higher

throughput and latency must be balanced

3D graphics pipeline



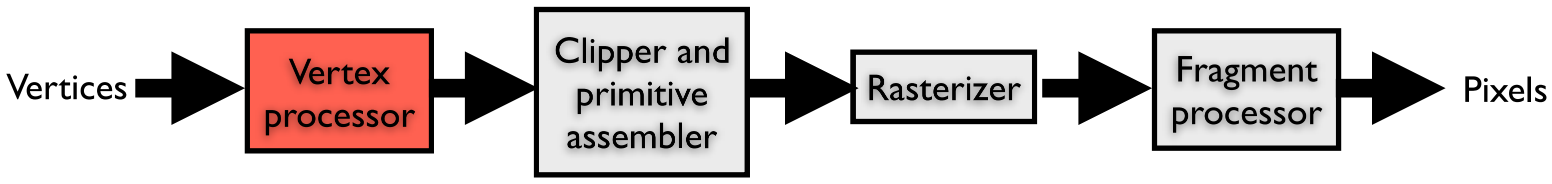
Geometry: primitives – made of vertices
Vertex processing: coordinate transformations and color
Clipping and primitive assembly: output is a set of primitives
Rasterization: output is a set of fragments for each primitive
Fragment processing: update pixels in the frame buffer

the pipeline is best when we are doing the same operations on many data sets
-- good for computer graphics!! where we process larges sets of vertices and pixels in the same manner

1. **Geometry**: objects – made of primitives – made of vertices
2. **Vertex processing:** coordinate transformations and color
3. **Clipping and primitive assembly:** use clipping volume. must be primitive by primitive rather than vertex by vertex. therefore vertices must be assembled into primitives before clipping can take place. Output is a set of primitives.
4. **Rasterization:** primitives are still in terms of vertices -- must be converted to pixels. E.g., for a triangle specificied by 3 vertices, the rasterizer must figure out which pixels in the frame buffer fill the triangle. Output is a set of **fragments for each primitive**. A fragment is like a **potential pixel.** Fragments can carry depth information used to figure out if they lie behind other fragments for a given pixel.
5. **Fragment processing:** update pixels in the frame buffer. some fragments may not be visible. texture mapping and bump mapping. blending.

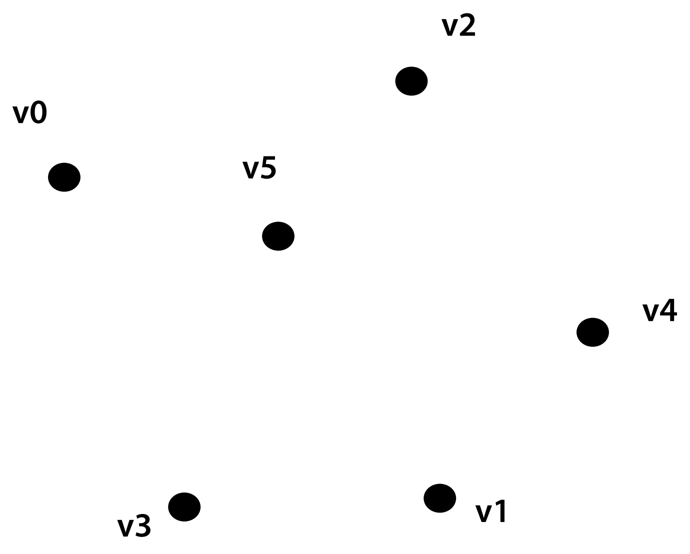
Graphics Pipeline

(slides courtesy K. Fatahalian)

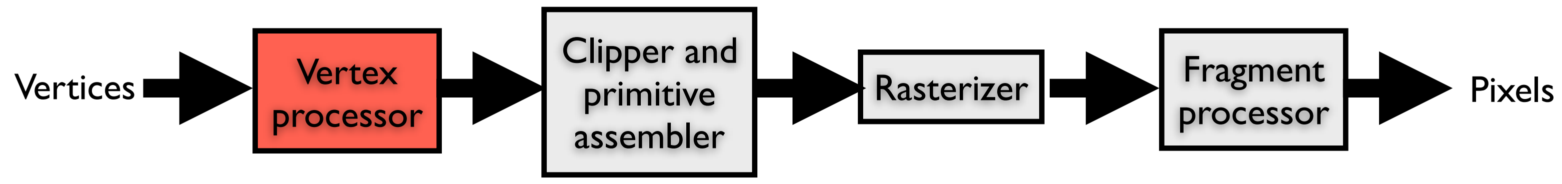


Vertex processing

Vertices are transformed into “screen space”



Vertices



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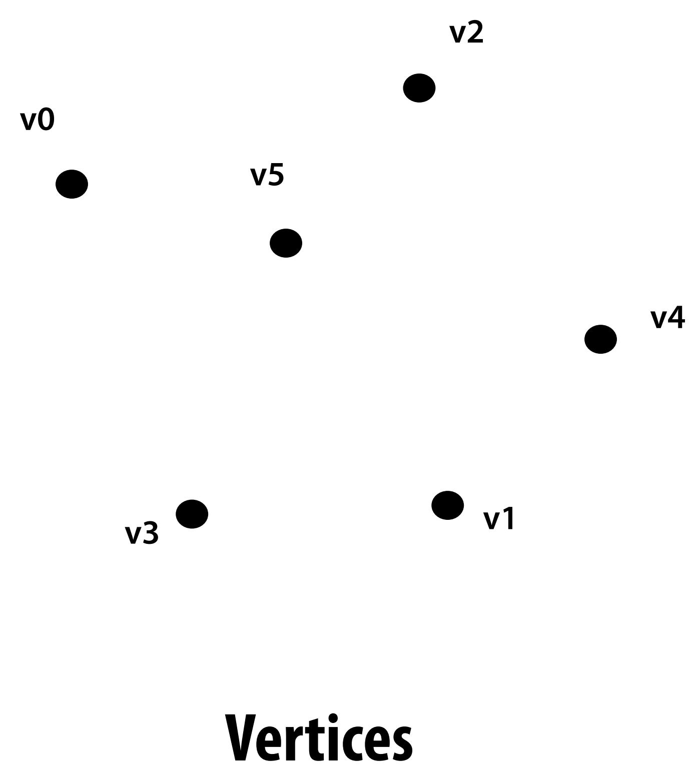
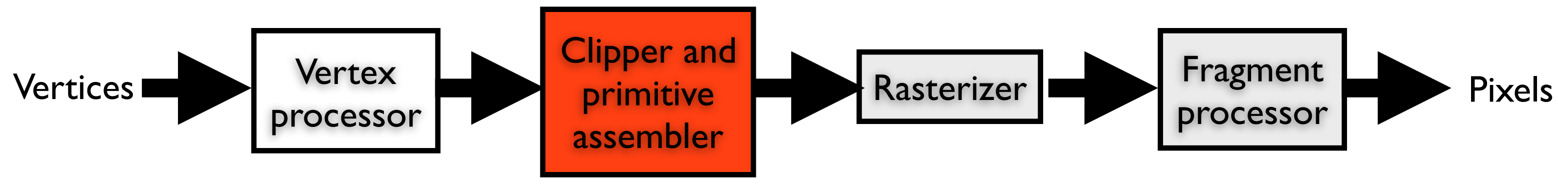
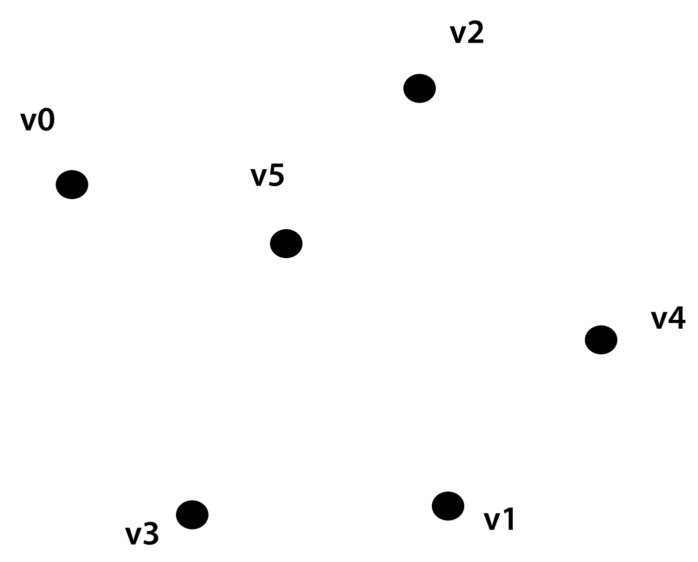


EACH VERTEX IS TRANSFORMED INDEPENDENTLY

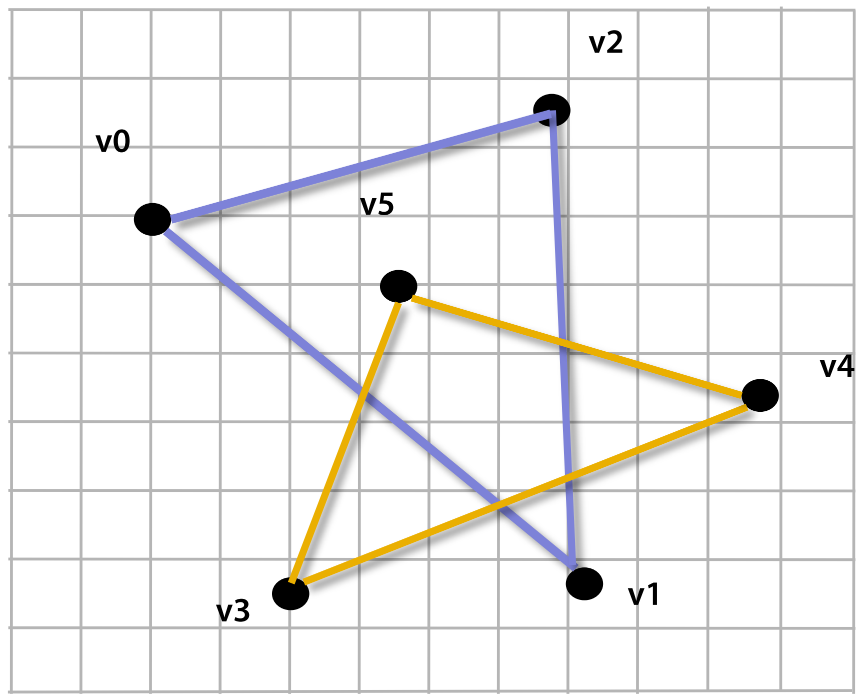


Primitive processing

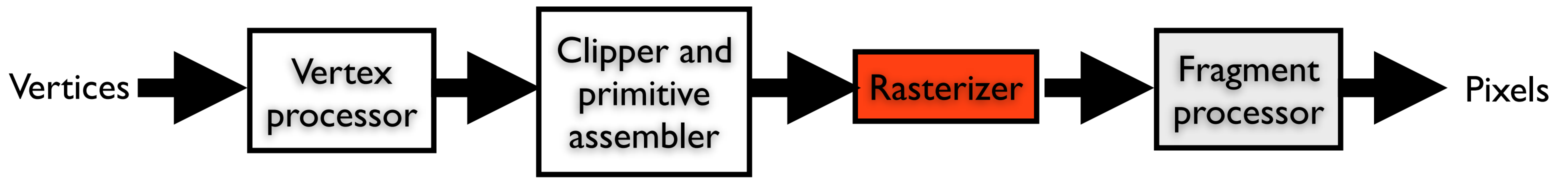
Then organized into primitives that are clipped and culled…



Vertices

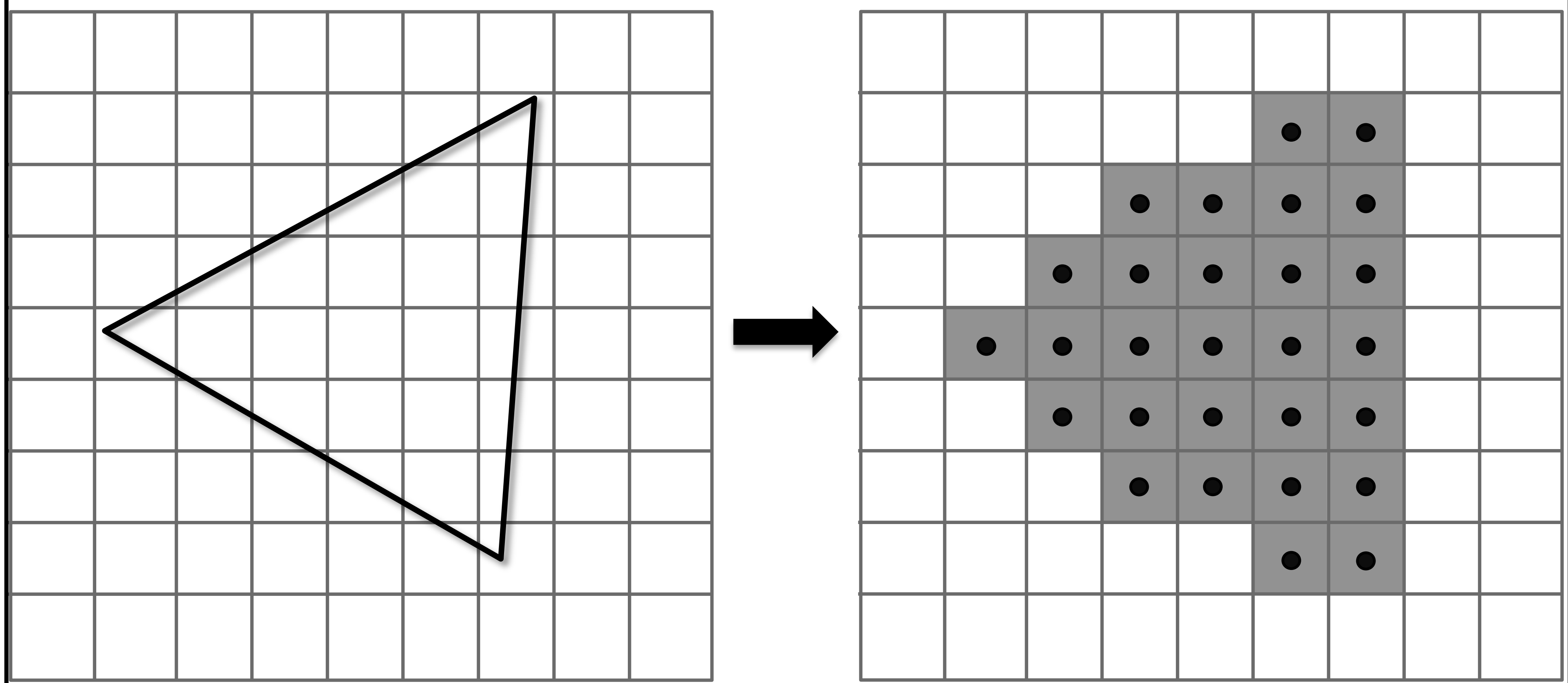


Primitives (triangles)

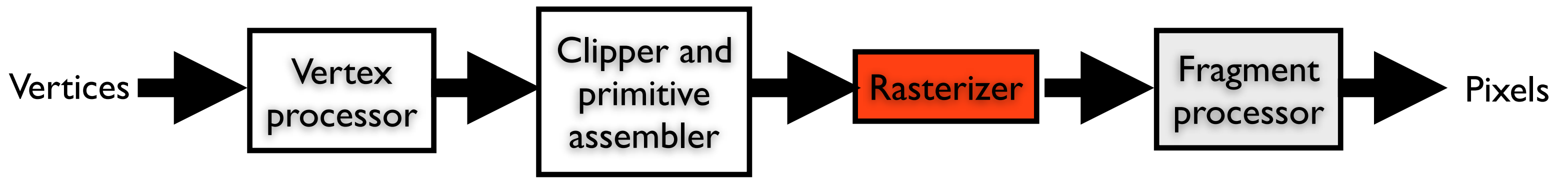


Rasterization

Primitives are rasterized into "pixel fragments"



Fragments



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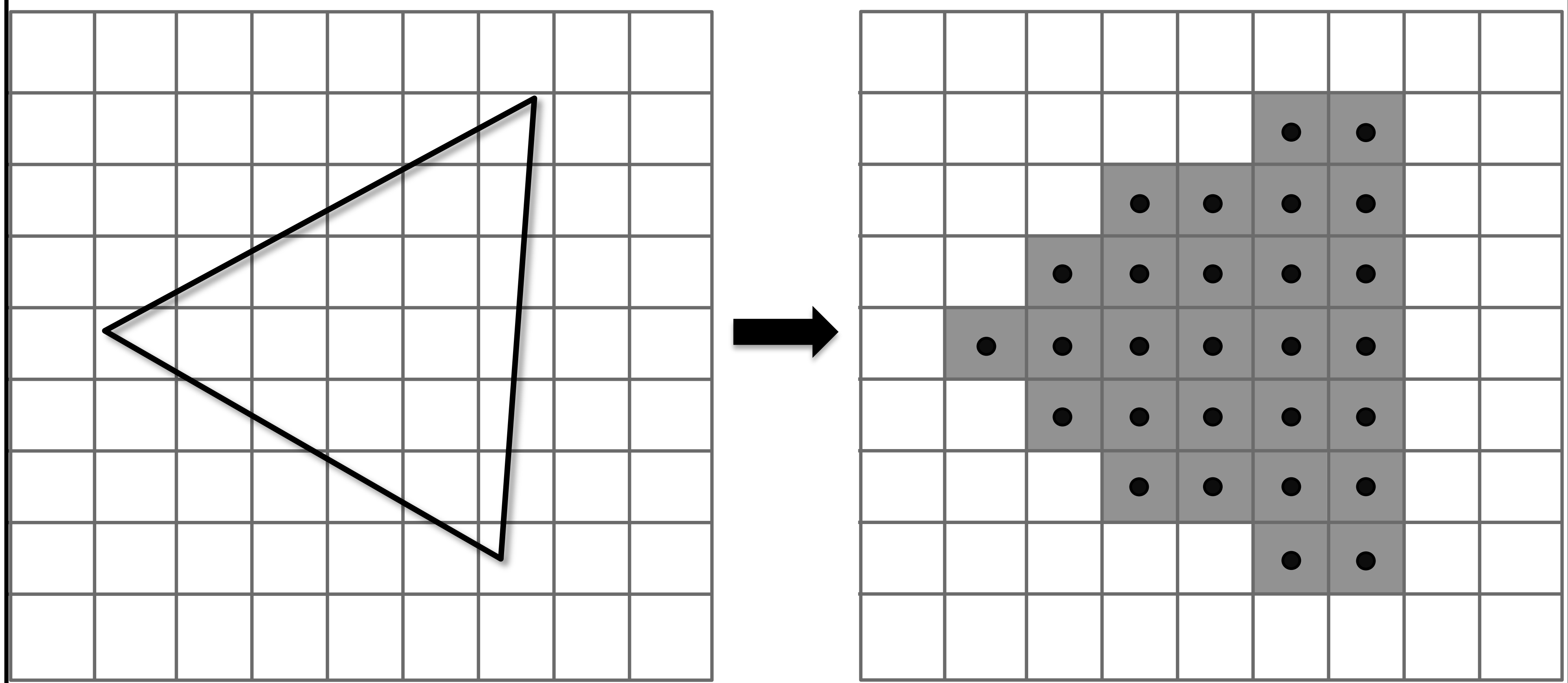
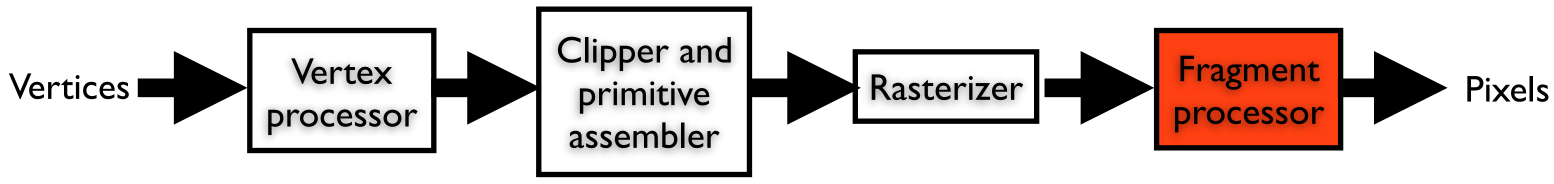
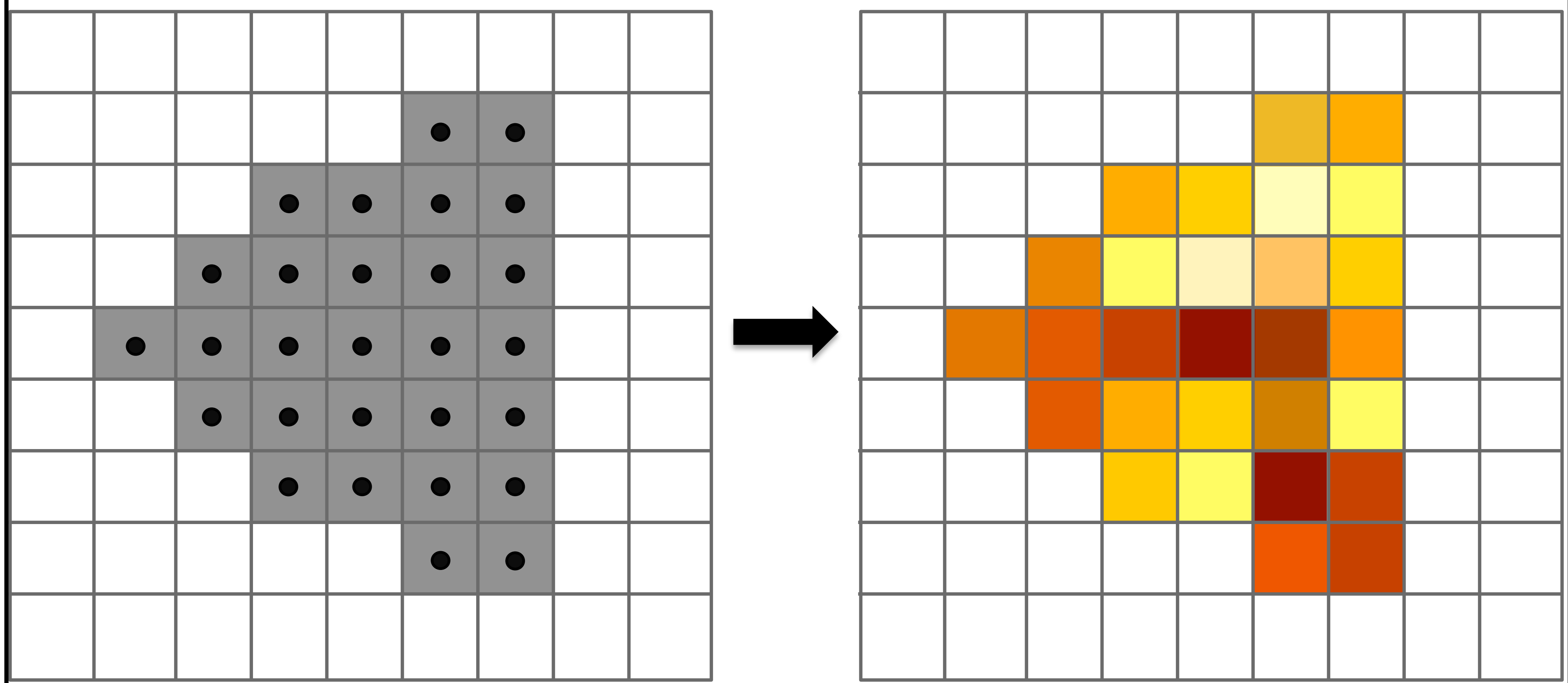


EACH PRIMITIVE IS RASTERIZED INDEPENDENTLY

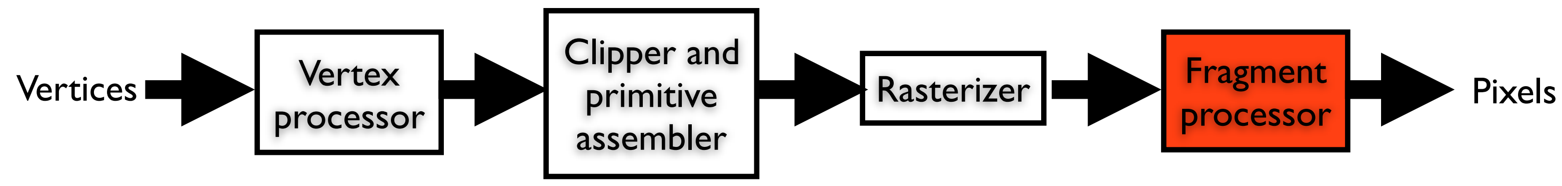


Fragment processing

Fragments are shaded to compute a color at each pixel



Shaded fragments



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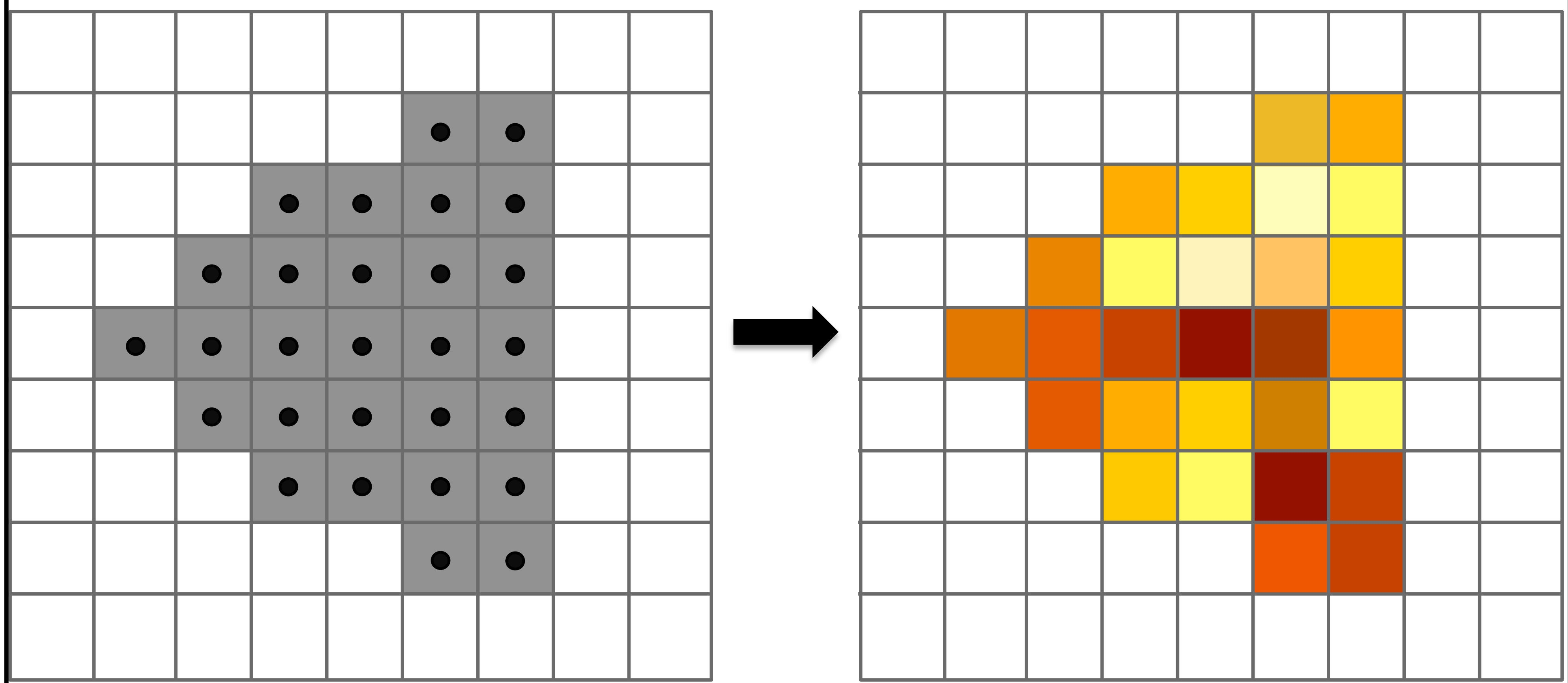
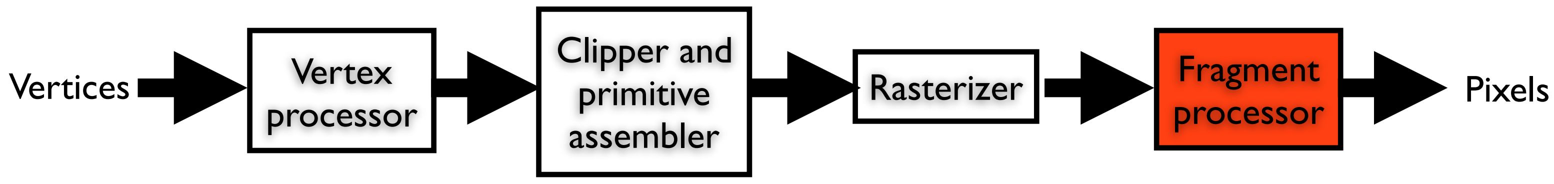
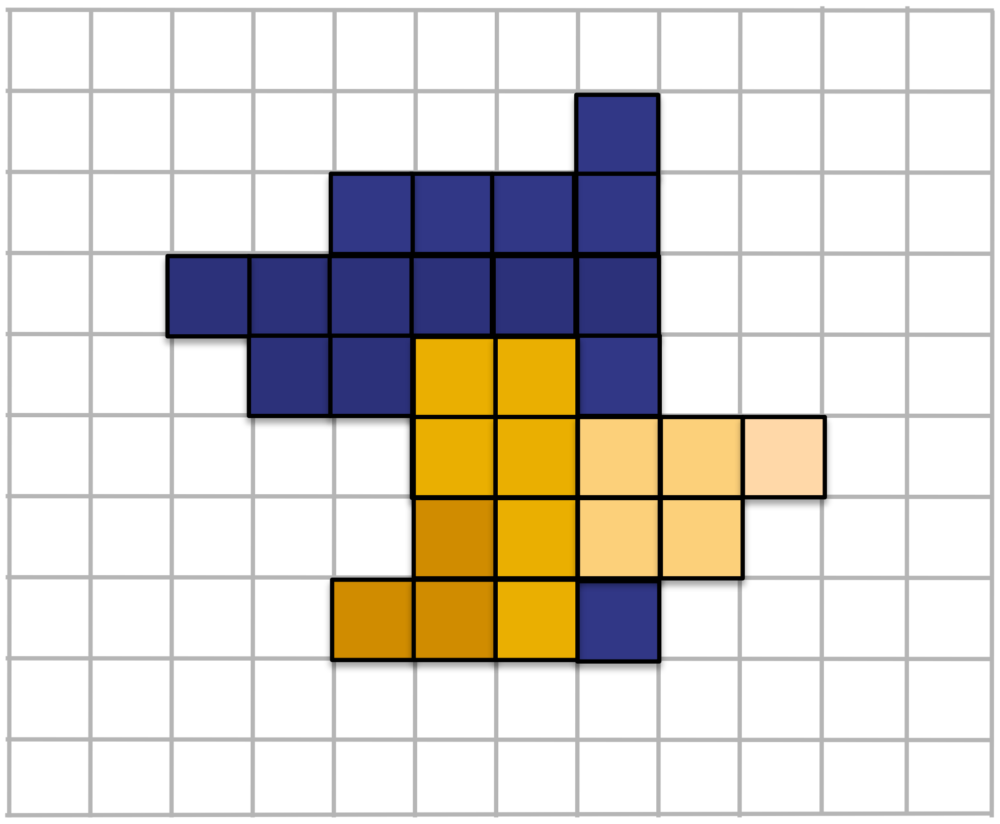


EACH FRAGMENT IS PROCESSED INDEPENDENTLY



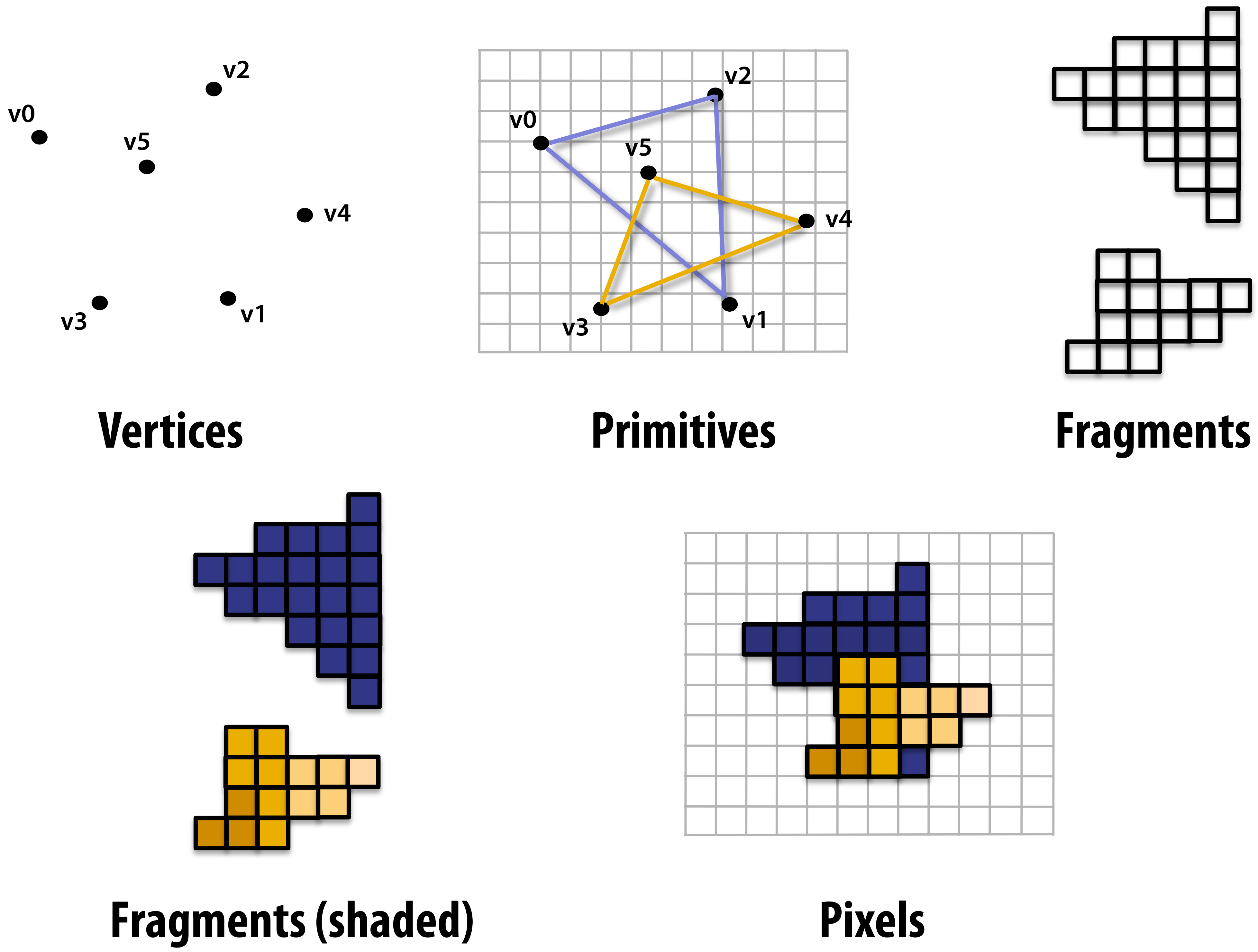
Pixel operations

Fragments are blended into the frame buffer at their pixel locations (z-buffer determines visibility)



Pixels

Pipeline entities



Graphics pipeline